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ORIGINAL PAPER

Models and form factors for stand volume estimation in natural forest ecosystems: a case study of Katarniaghat Wildlife Sanctuary (KGWS), Bahraich District, India

V. A. J Adekunle • K. N. Nair •A. K. Srivastava • N. K. Singh

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Abstract: In view of the difficulties in stand volume estimation in natural forests, we derived real form factors and models for volume estimation in these types of forest ecosystems, using Katarniaghat Wildlife Sanctuary as a case study. Tree growth data were obtained for all trees (dbh >10 cm) in 4 plots (25 × 25 m) randomly located in each of three strata selected in the forest. The form factor calculated for the stand was 0.42 and a range of 0.42–0.57 was estimated for selected species (density >10). The parameters of model variables were consistent with general growth trends of trees and each was statistically significant. There was no significant difference (p>0.05) between the observed and predicted volumes for all models and there was very high correlation between observed and predicted volumes. The output of the performance statistics and the logical signs of the regression coefficients of the models demonstrated that they are useful for volume estimation with minimal error. Plotting the biases with respect to considerable regressor variables showed no meaningful and evident trend of bias values along with the independent variables. This showed that the models did not violate regression assumptions and there were no heteroscedacity or multiculnarity problems. We recommend use of the form factors and models in this ecosystem and in similar ones for stand and tree volume estimation.

Keywords: natural forest; tree volume Estimation; biodiversity; tree height; forest inventory

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V. A. J Adekunle (✉)
Federal University of Technology, Dept of Forestry & Wood Technology, Akure, 234, Nigeria. E-mail: adekunlevaj@rediffmail.com

V. A. J Adekunle • K. N. Nair •A. K. Srivastava
National Botanical Research Institute (Council for Scientific & Industrial Research) Plant Diversity, Systematics & Herbarium Division, Rana Pratap Marg, Lucknow 226 001 India

N. K. Singh
Department of Forests, Sidhauli Forest Division, Sitapur, Uttar Pradesh, India

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Introduction

Stand volume estimation is important for decision making and sustainable management of forest resources. According to Cháidez (2009), bole volume estimates are useful in forest inventory because the volume of timber is the basic management unit of forests. Forest volume dictates the allocation of forest products such as poles for fences, sawn wood, pulp and paper, and plywood. Estimation of wood volume enables calculation of the monetary value of commodities and services that forests provide to society. For forest management and planning purposes, at national and stand levels it is vital to know the volume of the wood resources and their rates of growth (Atriell et al. 2010). With current, accurate data on timber volume, managers can make proper decisions and good forest governance will ensure sustainable forest management (Tonolli et al. 2011). Diamantopoulou (2006) saw tree volume estimation as an integral part of forest growth and yield forecasting. Ability to measure tree growth and volume can provide forest owners with an understanding of forest productivity and a basis for planning forest management actions and policies (Philip 1997; Shater et al. 2011).

Measurement of forest resources is required to quantify ecosystem services such as carbon sequestration, biodiversity conservation and water use. It is also required for carbon and biomass estimation for the REDD programme and global warning initiatives. Volume estimates are used to evaluate and monitor the commercial potential of a forest for timber and fuel wood production and for harvest potential. Information on growing stock is also essential for understanding the ecological dynamics and productive capacity of forest stands and allows managers the ability to manage stands within the limits of sustainability, as defined by their dynamics of growth (FAO 2005). The assessment of stem volume is of increasing global interest, especially in the context of the Kyoto protocol rules (Lindner and Kar-

jalainen 2007). Knowledge of tree growth parameters and yield is essential for effective forest management.

Data needed to estimate timber volume can only be collected through field inventory that is time consuming and expensive (Tonolli et al. 2011). Volumetric measurement of trees requires recording of diameter and height along the bole of each tree. Reducing the number of tree measurements can increase the productivity of field crews, reduce cost and increase the precision of estimates.

Models are used in forestry to support decision-making in forest management, estimation of growing stock, timber valuation and allocation of harvest areas (Adekunle 2007). Avery and Burkhart (2002) noted that volume equations can be used to estimate the average content of standing trees of various sizes and species. Akindele and Lemay (2006) reported that growing stock is usually expressed in terms of timber volume calculated from tree diameter and height. The use of volume equations can reduce the number of predictor variables to be measured.

While volume models have been developed for many plantation species, there are few models for natural forest species. Moser and Hall (1969) developed volume models for un-even age hardwood stands. Ek and Monserund (1974) developed spatial models for mixed forest ecosystems. The most recent models are those by Vanclay (1994) for tropical mixed forest, Adekunle et al. (2004) and Adekunle (2007) for protected forest ecosystems in southwest Nigeria and Akindele and LeMay (2006) for commercial hardwoods of Nigerian rainforests. Previous volume estimates were based on estimation of dbh and basal area. This is due to the difficulty of measuring height and diameter at the middle and top of standing trees. These variables are needed to compute volume using the formula of Husch et al. (2003), especially where a form factor is not available. Obtaining these variables for standing trees is difficult, inefficient and costly in tropical areas characterised by dense canopy, lianas and bushes, and where tree crowns are not visible through dense canopy cover (Riesco and Diaz-Maroto 2004). Data collection is labour- and technology-intensive and requires costly field mensuration techniques and tools, such as clinometers and Spegiel Relaskop. Less expensive tools such as the range finder are not as accurate, whereas the Spiegel Relaskop can be used to measure the middle and top diameters of standing trees with accuracy.

Volume estimates based only on dbh and total height are subject to error resulting from variation of the stem form of a tree (Socha, 2002; Socha and Kulej 2007). In natural forest, these differences arise from climatic and genetic factors (Socha and Kulej 2005 & 2007). When form factors are obtained for a location or tree species, stand volume estimation is more accurate. Using data on tree height and form factor, tree volume can be estimated with the formula V=g×h×f, where "V" is tree volume (in m^3), "g" is basal area at breast height (in m^2), "h" is tree height (in m), and "f" is the tree form factor. Use of form factors reduces error caused by equating a tree to a perfect cylinder.

We know of no form factors or models for volume estimation in the forest ecosystem on our study area. The sets of form factors and models in this study are the first to be developed and we hope they will be useful for stand volume estimation in this location and other similar forest ecosystems.

Materials and methods

Study area

Katarniaghat Wildlife Sanctuary (KGWS) is a tropical moist deciduous forest in the upper Gangetic Plains of Bahraich District, Uttar Pradesh, India (Behera et al. 2012). The sanctuary lies between latitude 27º41′ and 27º56′ N and between Longitude 81º48′ and 81º56′ E with elevation of 116–165 m. It is characterised by alluvial plain, wetlands, moist forest and grassland. It was gazetted a wildlife sanctuary in 1976. It is a dense forest 40 km long and 10 km wide, covering 440 km^2 along the India-Nepal border. Climatic variations typical of the plains of north India include extremes of heat and cold. Winter nights are cold and foggy and heavy dew falls regularly. Frosts occur generally in January. Nights remain cool and dew falls until late spring. Temperatures are hot between April and June before the commencement of monsoon rains in September (Behera et al. 2012). Average annual rainfall is about 1,300 mm. The sanctuary has five administrative beats. For the purpose of this study, each of the beats was regarded as a stratum. Three beats or strata, namely Murtiya, Balcha and Nishangara, were selected for study.

Sampling procedure

Twelve 25 × 25 m sampling plots were randomly located in the forest for data collection. Within each sample plot, measurement and identification were limited to all woody plants (dbh ≥ 10 cm) and the following data were collected for all trees for further analysis: (1) Diameter at breast height (dbh, 1.3 m above ground); (2) diameter over bark at the base, middle and merchantable top, measured using a Spiegel Relaskop; and (3) total and merchantable height measured using the Spiegel Relaskop. All tree species were identified to species. The density of each species was calculated. Total height was recorded from ground level to the top of the crown, while commercial or merchantable bole height was the length of the trunk from the ground to the merchantable height of the tree (FAO 2005).

Data analyses

Basal Area Calculation

Basal area of all trees in sample plots was calculated using the formula:

$$BA = (\pi D^2)/4 \tag{1}$$

where *BA* = Basal area (m^2), D = Diameter at breast height (cm) and л = pi (3.142). The total BA for each plot was obtained by summing tree BAs in each plot.

Volume Calculation

The volume of each tree was calculated for plots using Newton's

formula of Husch *et al* (2003):

$$V = (h/6)(A_b + 4A_m + A_t) \tag{2}$$

where: V = Tree volume (in m^3), A_b, A_m and A_t = tree cross-sectional area at the base, middle and top of merchantable height, respectively (in m^2) and h = total or merchantable or bole height (in meters). Bole, in this study, is defined as the main stem of the tree from the soil surface to the place where the first large branch protrudes the stem (Chaidez 2009). Plot volumes were also obtained by summing the volumes of all trees in each plot (Vp).

Basal area and volume per hectare were obtained by dividing the sum of basal area and volume respectively from the 12 plots by the number of sampling plots (12). This value was multiplied by the number of 25 ×25 m plot in a hectare (16).

Form factor estimation

Form factor is the ratio of tree volume to the volume a geometric solid (cylinder). The form factor (real or true form factor) was estimated for all species pooled and the selected seven species individually. Real form factor is the real volume divided by the volume of a cylinder with basal area equivalent to the tree basal area at breast height and height equal to the tree height (Zobeiri 2000). The real volume is the calculated volume using the measured tree growth variables. The cylindrical volume (V_c) of trees was first estimated:

$$V_c = \frac{\pi D^2}{4} h \tag{3}$$

Form factor was then obtained by division of the real tree volume (V_r) by cylindrical volume (V_c) as done by Gama et al. (2010) and Fadaei et al. (2008). Form factor was estimated for the entire stand by pooling all tree growth data and for individual species with >10 recorded stems.

Correlation coefficient calculation: Pairing of the growth parameters to examine linear relationships between them was carried out with Spearman correlation.

Volume model generation: Individual tree growth variables across all sample plots were used in models. We used the generalized allometric equation for mathematics and science and the linear regression models that followed the general Schumacher (1939) yield models. The Schumacher model is of the form: Y= f (A, SQ, SD) where Y = function of yield e.g. volume, A = age, SQ = function of site quality e.g. site index, height, SD = function of stand density e.g. diameter at breast height, basal area. Age in the original model was replaced by basal area.

The general allometry equation is given as:

$$Y = \beta X^{\alpha} \tag{4}$$

where Y is the dependent variable, β is a proportionality coefficient and α is the scaling exponential (slope of the line when plotted on logarithmic coordinate). This equation is regarded as a classical exponential function and is the most commonly used in biometric studies (Zianis and Mencuccini 2004; Cienciala et al. 2005). It contains two parameters (α & β) and a dependent variable. It was linearized to avoid the general problem of fitting non linear models by logarithmic transformation of both dependent and independent variables (Curtis 1967):

$$\ln V = \alpha + \beta \ln BA + \varepsilon \tag{5}$$

We used two other equations:

$$V = \alpha + \beta BA + \varepsilon \tag{6}$$

$$V = \alpha + \beta (D^2 H) + \varepsilon \tag{7}$$

where, V is the tree volume, BA is the basal area, α and β are regression coefficients to be determined, Ln is the natural logarithm, D is DBH (cm), H is tree height (m) and ε is an error term. While Equation 5 is a simple linear regression equation with basal area as the independent variable, equation 6 contains two parameters, but the dependence of volume was expressed as a composition of two independent variables, DBH and height, in the form $D^2 \times H$. This indicates volume when combined with π/4 and form factor. The calibrating data set included trees with large variation in diameters (10.2 to 63.5 cm), corresponding to young and old trees. But to avoid multicollinearity due to over-parameterization of the model, only variables highly correlated with estimated coefficients were included in model generation (Paulo et al. 2011). Models for estimating total stand volume were generated with equations 5-7 by combining data from all sample plots. Model 5 was adopted for estimating merchantable stand volume using pooled data and for volumes of selected species using their respective growth variables. These were species with high relative abundance (n ≥10) per hectare.

Assessment of the models

The models were assessed to test their plausibility and suitability for further use. The following statistical criteria were used:

Significance of regression (F - ratio): - The tabulated critical value of F at $p < 0.05$ was compared with the calculated F-ratio. Where F-calculated exceeded F-tabulated, equations were considered significant and useful for prediction.

Multiple correlation coefficient (R): R values >0.50 indicated a good fit.

Coefficient of determination (R^2): Models were acceptable at R^2 value >50%.

The regression standard error: The value must be relatively small for a model to be valid.

Validation of the models

We validated all the models by comparing predicted volumes with field results with statistical indices and graphical analyses

of residuals (Rupsys and Petrauskas 2010). All field data were divided into two sets. The first set (calibrating set), comprised growth variables from 323 trees (80%). These were used for generating the models (total and merchantable volume models) when all species were pooled. The second set (validating set) comprised tree data from 81 stems (20%). These were used for validating the models (Cooper and Weekes 1983). For selected species, especially those with few trees, all data were used for calibrating and validating. This was to ensure adequate data to represent different tree growth form and size within a species. Model outputs were individually compared with observed values using the Student t-test for paired means (Neter et al. 1996) and the simple linear regression equation (Amaro et al. 1998). In adopting the simple linear regression equation, the observed volume was the dependent variable while the model output was the independent variable.

For models with good fit, there should be no significant difference between the means of the observed and predicted volumes. For the simple linear regression equation, the intercept must approach 0 and the slope approach 1, and the model must be significant (p<0.05 or very high f-ratio value). There must be high correlation between the observed and predicted values, and the coefficient of determination values must also be very high (near 100%) and the standard error of estimates must be small (Onyekwelu and Akindele 1995; Amaro et al. 1998; Adekunle et al. 2004; Adekunle 2007). To verify that the residuals are normally distributed and not over or under estimated, residual plots were obtained for all allometric equations by plotting residual values against the independent variate i.e. the predicted volume (Ajit 2010). While there are many assumptions in the models, the essential multiple least-square regression assumptions are that the residuals should have normal distribution with zero mean and constant variance of the residuals.

We used one-way analysis of variance (ANOVA) to test differences in the outputs of the three models (Eqs 5–7) developed for estimating the total volume of all species. Where differences were significant, mean separation was calculated using Fisher's least significant difference (LSD). To further assess the accuracy of model predictions, the absolute and relative biases and the Root Mean Square Error (RMSE) were calculated for the models as follows (Vanclay 1994; Gadow and Hui, 1998):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_l)} \tag{8}$$

$$\mathbf{Bias} = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i) \tag{9}$$

$$\%Bias = 100 * \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)/n}{\sum_{i=1}^{n}\hat{y}_i/n} \tag{10}$$

where, y_i is the observed volume and $\hat{y}_i$ is the predicted volume (model output). The value must be relatively small for the model to be acceptable for volume estimation and for management purposes. These different approaches were adopted to ensure the reliability of the models for total and merchantable volume estimation by researchers.

Results

In total, 535 trees per hectare were recorded in sampling plots. They represented 25 species of 20 families. Species and family names, and summary growth variables are listed in Table 1. The most abundant species was *Mallotus philippensis* with 185 stems/ha, this was followed by *Shorea robusta* with 137 stems/ha. Leguminosae and Rubiaceae had the highest number of species (3 spp. each). Mean total height and mean DBH were 13.16 m and 33.20 cm, respectively. Basal area and volume per hectare were 63.20 m^2 and 647.96 m^3, respectively. There was wide variation between minimum and maximum values for all tree growth variables. Mean DBH ranged from 10.2–62.5 cm while mean height ranged from 5.3–23.4 m. Half of all species occurred at less than five trees per hectare. However, all species encountered in sample plots were used to estimate form factors and generating models.

Real form factor was estimated for all species as a group and for seven selected species whose relative abundance was >10 stems per hectare. Real form factor was preferred to the other types of form factor because it makes use of DBH. Table 2 shows form factors for the entire stand and the selected species with the total number of stems used in their calculation. Mean cylindrical volume for all trees was 2.37 m^3, while mean true volume was 1.20 m^3. The form factor for this forest was estimated at 0.52. Form factors for the selected tree species varied from 0.42 to 0.57, with the highest recorded for *Mp - Mallotus philippensis* and the lowest for *So - Schleichera oleosa and Te - Terminalia elliptica* . To eliminate the error variance and avoid over estimation common with the use of mean values, form factor was estimated for every stem before obtaining the mean for the stand and species. Values in Table 2 were calculated by using all stems encountered in the sampling plots.

Spearman correlation coefficients between paired tree growth variables are presented in Table 3. There was generally high and significant correlation among the variables (0.75 to 0.98). Highest correlation was recorded between the logarithm transformed values for basal area and volume, while the lowest correlation was between total height and basal area. There was also significant correlation between merchantable height and all other tree growth parameters (R ranged from 0.75 to 0.91).

Selected models for estimation of total and merchantable volume, and their assessment criteria are presented in Table 4. For the models involving all the species, 323 data from 25 trees species distributed in 20 families were involved in model calibration while 81 data from all the species and families were used for validation. The DBH of the trees ranged from 10.2 to 62.5cm. All selected models had significant correlation coefficients and coefficients of determination, small standard errors of estimates, and significant F-values. When species were pooled, the weighted model, with the combination of D^2H as predictor vari-

able had the highest correlation coefficient of 0.97 and R^2 of 93.6%. The logarithm-transformed model using LnBA as the predictor variable, a modification of the Schumacher-Hall model, had a correlation coefficient of 0.96 and the highest coefficient of determination of 95.1%. This model also had a high F-value of 6286.41and was rated the best for estimation of volumes of pooled and individual tree species.

Table 1: List of tree species, families and growth parameters of trees involved in model generation

Family	Species	n/ha	MHt	MDbh	Ba/ha	Vol/ha
Annonaceae	*Miliusa tomentosa* (Roxb.) J. Sinclair	1	6.8	10.20	0.01	0.03
Boraginaceae	*Ehretia laevis* Roxb.	44	7.98	18.53	1.28	5.76
Combretaceae	*Terminalia elliptica* Willd.	41	23.28	48.93	8.27	111.39
Dilleniaceae	*Dillenia pentagyna* Roxb.	7	15.04	37.93	0.87	8.42
Dipterocarpaceae	*Shorea robusta* Gaertn.	137	20.39	53.15	33.74	391.27
Ebenaceae	*Diospyros exsculpta* Buch.- Ham.	5	15.23	44.30	0.85	6.98
Euphorbiaceae	*Bridelia retusa* (L..) A. Juss.	1	18.6	45.50	0.22	2.74
	Mallotus philippensis (Lam.) Mull. Arg	185	8.27	17.20	4.61	22.03
Leguminosae	*Bauhinia malabarica* Roxb.	1	5.3	16.50	0.03	0.06
	Desmodium oojeinense (Roxb.) H. Ohashi	5	16.8	42.65	0.81	5.99
	Pongamia pinnata (L.) Pierre	1	12.1	21.00	0.05	0.24
Lauraceae	*Litsea monopetala* (Roxb.) Pers.	4	15.07	26.40	0.25	3.14
Lythraceae	*Largerstroemia parviflora* Roxb.	11	16.64	34.19	1.03	9.62
Malvaceae	*Kydia calycina* Roxb.	1	7.3	21.20	0.05	0.21
Moraceae	*Ficus benghalensis* L.	5	12.18	61.18	2.12	8.85
Myrtaceae	*Syzygium cumini* (L.) Skeels	28	14.19	39.53	4.19	37.39
Rhamnaceae	*Rhamnus triquetra* (Wall.) Brandis	1	16.7	28.2	0.08	0.83
Rubiaceae	*Haldina cordifolia* (Roxb.) Ridsdale	4	9.4	21.4	0.17	1.00
	Hymenodictyon orixense (Roxb.) Mabb.	1	6.3	13.5	0.02	0.04
	Mitrygyna parvifolia (Roxb.) Korth.	3	14	39.5	0.33	2.21
Rutaceae	*Aegle marmelos* (L.) Correa	7	10.92	27.82	0.43	2.68
Sapindaceae	*Schleichera oleosa* (Lour.)Merr.	13	13.68	41.36	2.26	15.11
Sapotaceae	*Madhuca longifolia* (L.) J. F. Macbr.	1	9.20	14.9	0.02	0.08
Ulmaceae	*Holoptelea integrifolia (*Roxb.) Planch.	3	18.00	62.5	0.82	6.14
Verbenaceae	*Tectona grandis* L.f.	24	10.88	14.34	0.40	2.07
	Total	535	13.16*	33.20*	63.28	647.96

* These are mean values and not total of the column

Table 2: Form factors for stand volume estimation

Species	No of stems	Form factor
All species	404	0.52
Ehretia laevis	33	0.53
Mallotus philippensis	139	0.57
Schleichera oleosa	10	0.42
Shorea robusta	103	0.50
Syzygium cumini	21	0.49
Tectona grandis	18	0.44
Terminalia elliptica	31	0.42

The R-values of the models for total volume of individual species ranged from 0.84 to 0.99, with the minimum for Mp and the maximum for So. The coefficient of variation followed the same trend, ranging from 70.7% to 97.7%. The least R^2 was also obtained for Mp while the highest was for So. All models for merchantable volume prediction were highly significant, with relatively small standard error. An R value of 0.98 was obtained when all species were pooled and values ranged from 0.93 to 0.99 for the selected species. R^2 for all species was 95.1%, ranging from 86.6 to 98.7 for the separated species (Table 4).

Table 3: Spearman correlation matrix for tree growth variables in KGWS

	DBH (cm)	Total height (m)	Basal area (m²)	Ln Basal area	Total volume (m³)	Ln total Volume	Mht
dbh (cm)	1.00						
Total height (m)	0.84	1.00					
Basal area (m²)	0.96	0.75	1.00				
Ln Basal area	0.96	0.85	0.85	1.00			
Total volume (m³)	0.87	0.82	0.90	0.77	1.00		
Ln total Volume	0.94	0.91	0.82	0.98	0.80	1.00	
Merchantable height (m)	0.84	0.90	0.75	0.85	0.82	0.91	1.00

Table 4: Models generated for total and merchantable stand volume estimation and their assessment criteria for pooled and selected species in KGWS

Spp	Total Volume (V_t)					Merchantable Volume (V_m)				
	Models	R	R^2	SE	F-ratio*	Models	R	R^2	SE	F-ratio*
All	V_t = 11.61Ba -0.16	0.91	82.8	0.78	1550.04	NA				
All	LnV_t=2.76+1.33LnBa	0.96	95.1	0.36	6286.41	LnV_m=2.40+1.33LnBa	0.98	95.1	0.36	6286.41
All	V_t=0.05+ 0.37D^2H	0.97	93.6	0.48	4630.55	NA				
El	LnV_t=2.36+ 1.26LnBa	0.92	83.9	0.32	161.08	LnV_m=2.00+1.26LnBa	0.92	83.9	0.32	161.08
Mp	LnV_t=2.09+1.16LnBa	0.84	70.7	0.38	329.83	LnV_m=1.73+1.16LnBa	0.84	70.6	0.38	329.83
So	LnV_t=2.26+ .25LnBa	0.99	97.7	0.28	342.72	LnV_m=2.80+ .25LnBa	0.99	98.7	0.16	1079.06
Sr	LnV_t=2.85+ 1.37LnBa	0.95	89.5	0.32	863.47	LnV_m=2.48+ 1.36LnBa	0.95	89.5	0.32	863.90
Sc	LnV_t = 2.50 + 1.27LnBa	0.98	96.7	0.28	454.48	LnV_m=2.14 + 1.27LnBa	0.98	96.2	0.28	454.48
Tg	Ln V_t = 3.99+1.59LnBa	0.97	93.4	0.16	257.84	LnV_m = 3.63+ 1.59LnBa	0.97	93.4	0.28	227.84
Te	LnV_t = 3.21 + 1.43LnBa	0.93	87.4	0.30	200.46	LnV_m = 2.85 + 1.43LnBa	0.93	87.4	0.30	200.46

Ba = Basal area (m^2), D = Diameter at breast height, H = Total height, Ln = Natural logarithm

El - Ehretia laevis, Mp - Mallotus philippensis.,), So - Schleichera oleosa Sr - Shorea robusta, Sc - Syzygium cumini, Tg - Tectona grandis and Te - Terminalia

* F-ratios were significant for all the models (p<0.05)

The models provided realistic estimates of timber volume. All model estimates were compared to observed data using numerical and graphical analyses of residuals. Validation results are presented in Table 5 while the results of the simple linear regression equations are presented in Table 6. There were no significant differences in the observed versus predicted volumes for all models. Simple linear regression confirmed that the models had adequate fit. The R-values for the three models for total stand volume estimation were 0.89, 0.90 and 0.97 for the simple linear model, logarithm transformed model, and model with combined variables, respectively, and the R^2 values were 79.3, 81.4 and 93.1% for the three models, respectively. R values for selected species ranged from 0.87 to 0.98 while R^2 ranged from 77.4 to 96.1. Model results for merchantable volume followed the same trend with R and R^2-values of 0.93 and 87.4%, respectively, and values ranging from 0.95 to 0.98, and 90.0 to 97.8% for R and R^2, respectively. R and R^2 values were very high, with very small SEE and significant equations indicated by high F-values. In addition, all coefficients were significant, with intercepts approaching zero and slopes approaching 1. Some regression coefficients (intercepts) had the expected negative values. Graphic presentation of residual plots against predicted values (total and merchantable values for pooled and individual species) shown in Figs 1 and 2 indicated homogenous variance. There was no identifiable trend of scatter-plots. This showed that the models did not violate any assumptions and there were no heteroscedacity problems. There were no multicollinearity problems with these models since only a single predictor variable was involved in their simulation.

Table 5: Validation results of models for predicting the total and merchantable volume in KGWS with Student's t-test

Species	Total Volume (V_t)						Merchantable Volume (V_m)				
	Mean observed Volume	Mean predicted volume	df	t-stat	t-critical	p-value	Mean observed Volume	Mean predicted volume	t-stat	t-critical	p-value
All species	1.35	(1) 1.33	80	0.186	1.99	0.853	NA				
		(2) 1.27	80	0.854	1.99	0.395	0.94	0.89	0.796	1.99	0.428
		(3) 1.22	80	1.801	1.99	0.075	NA				
El	0.131	0.129	32	0.219	2.037	0.828	0.092	0.090	0.262	2.037	0.795
Mp	0.118	0.114	138	1.387	1.977	0.167	0.083	0.080	1.481	1.977	0.141
So	1.133	1.157	9	0.199	2.262	0.847	0.822	0.857	0.345	2.262	0.738
Sr	2.849	2.791	102	0.435	1.983	0.664	1.993	1.947	0.505	1.983	0.615
Sc	1.34	1.22	20	0.703	2.086	0.490	0.934	0.934	0.999	2.086	0.329
Tg	0.086	0.085	17	0.205	2.110	0.840	0.060	0.059	0.265	2.110	0.794
Te	2.695	2.666	30	0.233	2.042	0.817	1.886	1.860	0.294	2.042	0.386

El - Ehretia laevis, Mp - Mallotus philippensis.,), So - Schleichera oleosa Sr - Shorea robusta, Sc - Syzygium cumini, Tg - Tectona grandis and Te - Terminalia elliptica

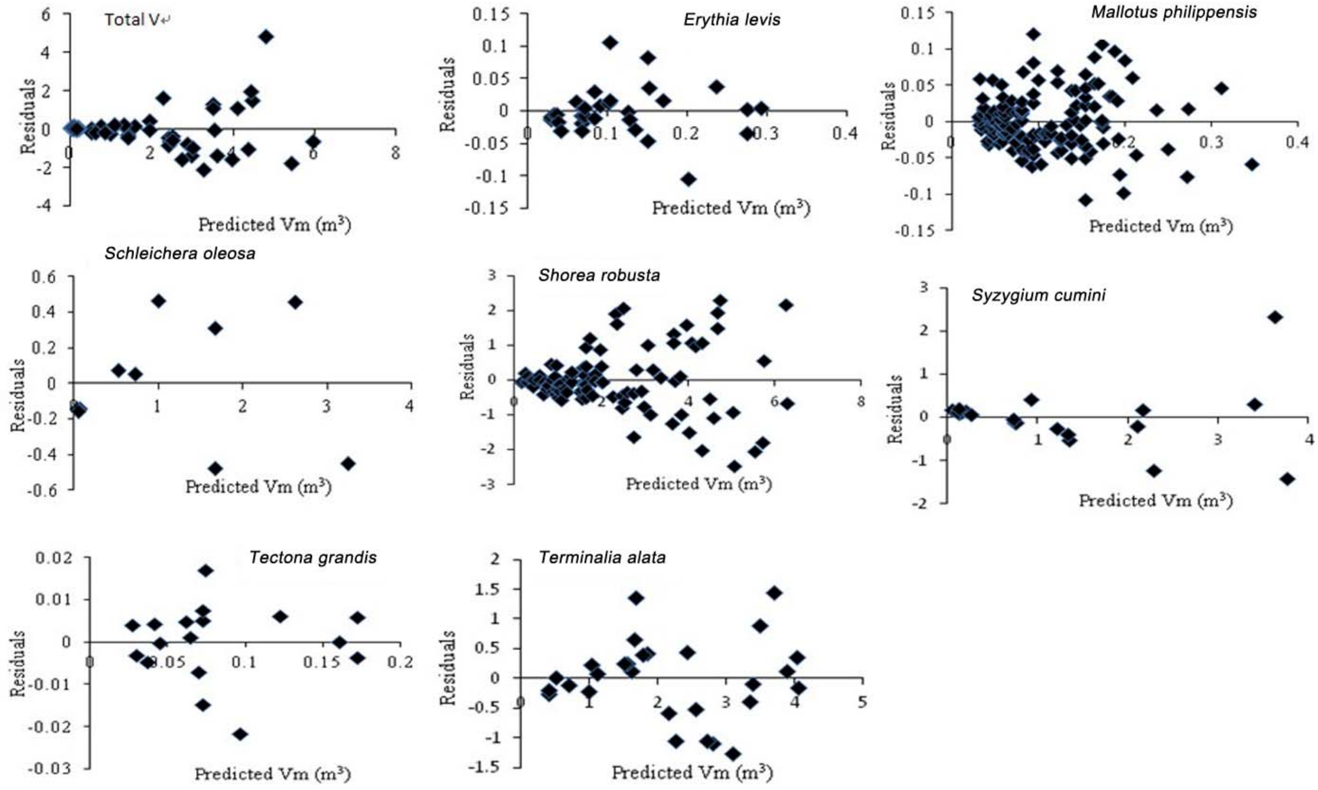

Fig. 1 Predicted stand total V (m3) and Residual plot for allometry model validation

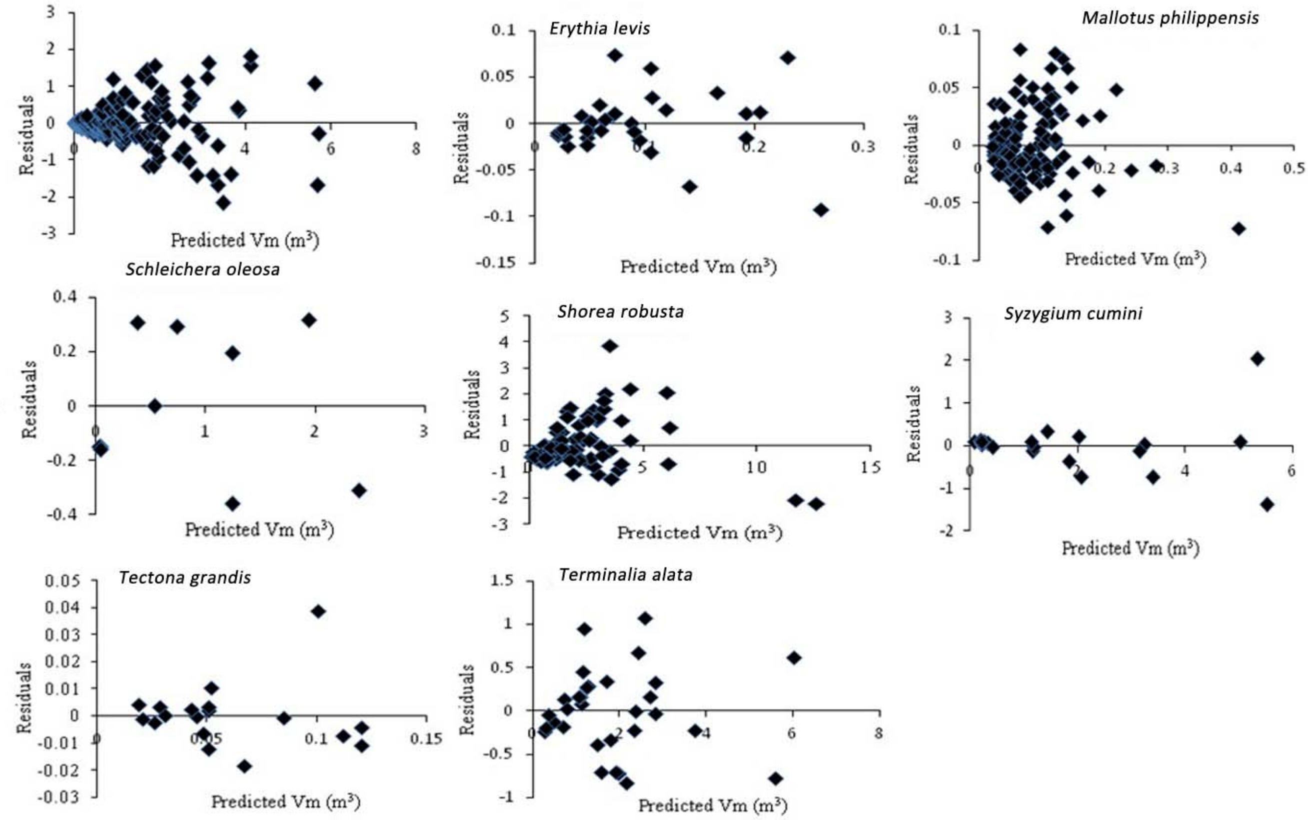

Fig. 2 Predicted merchantable V (m^3) and Residual plot for allometry model validation

Table 6: Validation results for selected models for predicting total and merchantable volume in KGWS with simple linear regression

Species	Total volume						Merchantable volume					
	Intercept	Slope	r	r^2 (%)	SE	F-ratio	Intercept	Slope	r	r^2 (%)	SE	F-ratio
All	(1) -0.141	1.202	0.89	79.3	0.91	301.99	NA					
species	(2) -0.079	1.128	0.90	81.4	0.86	345.18	-0.055	1.124	0.90	80.5	0.62	2207.51
	(3) -0.159	1.232	0.97	93.1	0.52	1073.63	NA					
El	0.010	0.953	0.89	79.5	0.04	108.94	0.012	0.885	0.87	75.5	0.03	95.50
Mp	0.011	0.948	0.87	76.5	0.04	446.29	-0.008	0.950	0.87	76.5	0.03	446.29
So	0.15	0.85	0.94	88.8	0.36	63.18	0.130	0.906	0.99	97.8	0.28	354.60
Sr	0.061	0.80	0.88	77.4	1.22	346.88	0.423	0.806	0.88	77.4	0.85	343.88
Sc	-0.17	1.24	0.91	82.0	0.73	86.35	0.003	0.999	0.99	99.4	0.003	259.32
Tg	-0.002	0.939	0.98	96.1	0.01	370.41	-0.001	1.037	0.95	89.8	0.16	141.26
Ta	0.104	0.988	0.94	87.6	0.67	204.41	0.275	0.923	0.97	94.5	0.55	496.12

El - *Ehretia laevis,* Mp - *Mallotus philippensis* (So - *Schleichera oleosa ,),* Sr - *Shorea robusta,* Sc - *Syzygium cumini ,* Tg - *Tectona grandis* and Te - *Terminalia elliptica*

RMSE, biases and % biases are presented in Table 7. For pooled-species models, RMSE for total volume ranged from 0.01 to 1.07. RMSE ranged from 0.01 to 0.58 for the selected species. The relative and % biases also ranged from 0.01 to 0.12 and 0.86 to 9.68%, respectively for pooled-species models. The values for the selected species ranged from 0.01 to 0.12 and 2.04 to 9.68% for biases and % biases, respectively. For merchantable volume estimation models, RMSE was 0.50 for pooled species and ranged from 0.01 to 0.46 for selected species. The relative biases and % biases ranged from 0.01 to 0.06 and 0.05 and 6.26, respectively (Table 7). These values were relatively very small and they confirmed that the models gave accurate predictions with manageable error.

Table 7. Model validations with some statistical indices (RMSE, Biases % Biases and Standard Error of Estimate)

Species	Total Volume				Merchantable volume			
	RMSE	Biases	%Biases	SEE	RMSE	Biases	%Biases	SEE
All species	(1) 0.10	0.01	0.86		NA			
	(2) 0.68	0.08	5.97		0.50	0.06	6.26	
	(3) 1.07	0.12	9.68		NA			
El	0.01	0.00	1.41		0.01	0.00	1.68	
Mp	0.06	0.00	4.16		0.04	0.00	4.52	
So	0.08	-0.02	-2.07		0.11	-0.04	-4.08	
Sr	0.58	0.06	2.04		0.46	0.05	2.33	
Sc	0.54	0.12	9.62		0.00	0.00	0.05	
Tg	0.00	0.00	1.31		0.00	0.00	0.93	
Ta	0.16	0.03	1.09		.14	0.03	1.39	

Abbreviations of species refer to Table 6.

Discussion

Plant species diversity and evenness of this forest was described by Tripathi & Singh (2009) and Maliya & Datt (2010). All recorded plant species are indigenous and they are tropical hardwood species that are important for rural livelihood and national development. Their assessment therefore is crucial to the sustainable management of the resources and in carbon sequestration. Tree growth data from 404 stems recorded in sampling plots were used to estimate the form factor for the forest. For individual species, the number of stems per sampling plot ranged from 10 to 139. Mean volume estimates were similar when using the form factor or when using the observed volume for pooled species and selected individual species. The efficacy of form factor for volume estimation has been reported for plantation species. Gama et al. (2010) estimated the volume of Eucalyptus stems with a form factor between 0.42 and 0.46. Fadei et al. (2010) adopted a form factor of 0.47 to estimate the volume of loblolly pine in Iran. A range of 0.44 to 0.49 was used by Socha and Kulej (2007) for European Larch in Poland. The form factor range from 0.42 to 0.57 obtained for this forest lies within the range used by these workers. The variation in form factor by species is due to the variation in species composition and tree size. Several factors, including genetics, environmental conditions and geographical locations were listed as factors that can affect the growth and form of plants (Socha and Kulej 2005, 2007).

While it is useful to develop growth models for each of the many species found in tropical forests, data for individual species are seldom adequate. Most species occur at low frequency (Adekunle et al. 2004). Vanclay (1995) and Akindele and LeMay (2006) reported that it is common to have many species with insufficient data for reliable parameter estimation. They suggested grouping species that are in some sense similar as the best way to provide unbiased prediction equations. For this reason, we pooled all species encountered in the sampling plots. Models were also developed for species with appreciable numbers of trees. Considering the sources of error in height and stem diameter measurement, it is necessary to develop volume estimation models using a variable, such as DBH, which can be accurately measured in the field. To estimate stand volume with the recommended models therefore, only DBH will be required from the field. This method is fast, requires less work, and is therefore cost efficient in forest inventories (Segura and Kennien2005). Zianis and Mencuccini (2004) reported that the single metric most commonly used for tree allometry is diameter, as is evident in the syntheses (279 equations) they compiled. Ketterings et al. (2001) also supported the claimed that height measurement in natural forest can be tedious and might not explain more of the variance.

We developed and tested models that could be used for total and merchantable or bole volume estimation. All the assessment criteria revealed that the simulated models had good fit. The statistical fits were generally good. We recommend use of these equations based in part on the results of the paired-mean student t-test. There were no significant differences between observed and predicted volumes. The paired-mean t-test was also used in several studies to test the

adequacy of models. The second criterion was the use of the simple linear regression equation. There was a strong relationship (high R values) between the observed and predicted volumes, high R^2, significant F-ratio and small standard error of the regression equations. Also, the slopes approached zero while the intercepts approached 1.0, and they were all significant (p<0.05), as calculated by Akindele & LeMay (2006) and Adekunle (2007) for the tropical forest ecosystem of SW Nigeria. SE, RMSE, biases and % biases also confirmed predictive precision, accuracy, and normality. The values were very small and similar to what were obtained by Sonmez et al. (2009) and Adam and Csalovics (2010). This was supported by the report of Adekunle (2006) that standard error of estimate is a good measure of overall predictive value of regression equations (). (Glantz and Slinker (2001) also noted that it is a common measure of goodness of fit in regression models, with low values indicating better fit.

Models developed by Clutter et al. (1983) and Segura & Venegas (1999) only predicted commercial stem volumes. But Segura and Kennien (2005) developed allometric models for predicting both total and commercial volumes as done in this study. They obtained a strong correlation between Ln D and Ln H (0.94). The R^2 for their equations ranged from 0.63 to 0.66 for models for predicting commercial volumes and 0.76–0.81 for those predicting total volume. They also obtained RMSE that ranged from 0.274 to 1.80 for commercial volume prediction models and 0.166 to 1.97 for total volume prediction models. Sönmez et al. (2009) and Adam and Csalovics (2010) also adopted these statistical indices to validate their tree growth models and they obtained similar results. Brandeis et al. (2005) also derived tree volume equations for estimating merchantable volume from inventory data by first calculating stem volume using a geometric formula. They fitted the equations for all species as a group and some selected individual species as done in this study. For a group of 1,247 stems of 102 species, with minimum DBH of 12.5 cm, their R^2 ranged from 0.73 to 0.99, which was in the range calculated in this study.

The conformity to regression assumptions when tested with the probability plot of residual and predicted values conformed to the observation of Ajit (2010). The scatter-plots were consistent with the results of other statistical indices for validation. This shows that the regression assumptions were not violated. Other tree growth modelling studies, including Andreassen and Tomter (2003), Mabvurira and Miina (2002), Zhao et al. (2004), Trasobares and Pukkala (2004), and Sonmez et al (2009) also observed no constant variance of residuals, an inevitable phenomenon for forest populations due to the nature of the growth process. Akindele and Leymay (2006) recommended the use of weighted values but they did not use the weighted least regression to model. A problem could only occur if the degree of variation is high enough and evident in predicting estimates of basal area growth (Sonmez et al. (2009). But the test criteria show that this bias trend is not meaningful and did not result in heteroscedastic.

Conclusion and recommendation

Volume estimation is critical to forest resource management. Estimation of this parameter is usually confounded by factors such as lack of equipment for measurement of tree height and upper diameter, difficulties in measurement of tree height in tropical forests, the complex architectural structure of tropical forests and the high cost of inventory work. To avoid this problem, form factor and models for total and bole volume estimation were developed in this study. The form factors and the fitted volume models yielded the statistical outcomes needed for further use. They are sound for volume estimation in this study area and at similar sites. If used outside our study area, some precautions must be taken. The models are recommended for further use.

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